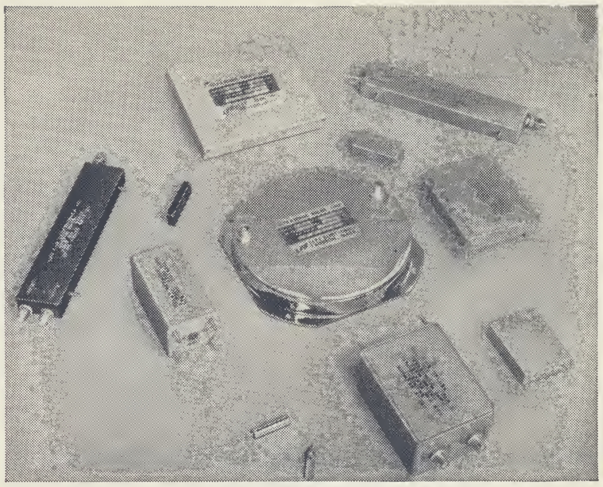
# LFE DELAY LINES
## *from 5 nanoseconds to 2 seconds*



LFE offers to the designer of guidance systems, computers, MTI Radar, ECM Systems, and other applications a wealth of technical know-how dating back to 1947 — which now makes possible the most accurate, reliable and advanced custom engineered Delay Lines for laboratory and operational use.

Delay Lines from LFE Advanced Components are ideally suited to both military and commercial applications, and where severe environmental conditions prevail.

Application of the latest technological advances and manufacturing techniques insures high reliability and stability at low cost and in the minimum of space.

For your complete Delay Line needs, LFE Advanced Components provides:

**MAGNETOSTRICTIVE DELAY LINES**
Torsional and longitudinal — Fixed, adjustable and variable — Delays from 2 Microseconds to 10 Milliseconds — RZ Bit rates up to 4 Megacycles — Complete RZ and NRZ memories incorporating electronics.

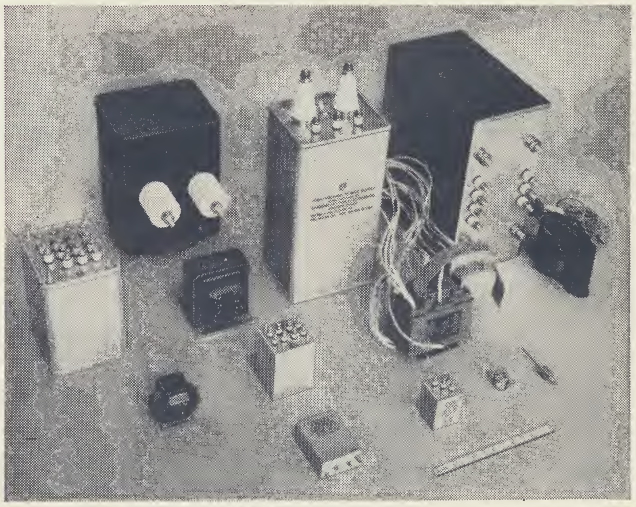
**PRECISION RANGE MARKERS**
Single and double ended — Pulse spacing 1.0 to 100 Microseconds — Center frequencies up to 500 Megacycles.

**DIGITAL ULTRASONIC DELAY LINES**
Fixed, tapped, adjustable and multiple channel — Delays from 0.5 to 1,000 Microseconds — Bit rates (RZ) up to 50 Megacycles — Complete RZ or NRZ serial memory systems incorporating electronics.

**SOLID ULTRASONIC DELAY LINES**
Fixed, tapped and variable — Fused quartz or zero temperature coefficient glass delay media — Quartz or ceramic transducers — Delays from 0.3 Microseconds to 10 Milliseconds — Center frequencies from 1 to 100 Megacycles — Matched delay line sets — Delay line packages incorporating drivers, amplifiers, detectors and temperature control circuits.

**ELECTROMAGNETIC DELAY LINES**
Lumped - and distributed - constant — Fixed, tapped, variable and modular — Hermetically sealed or encapsulated — Time delays ranging from 5 Nanoseconds to 2 Seconds — Impedance from 10 ohms to 10,000 ohms — Delay to rise time ratio up to 200 to 1.

# TRANSFORMERS



Complete production facilities are available for environmental testing of components to military specifications. Advanced Components transformers include: Pulse — Audio — Power — Reactors — High Q and RF Coils — Electric Wave Filters — Magnetic Amplifiers and power supply specialties.

LFE Advanced Components offers technical assistance and engineering advice and service in determining your exact delay line and transformer requirements in the most economical way.

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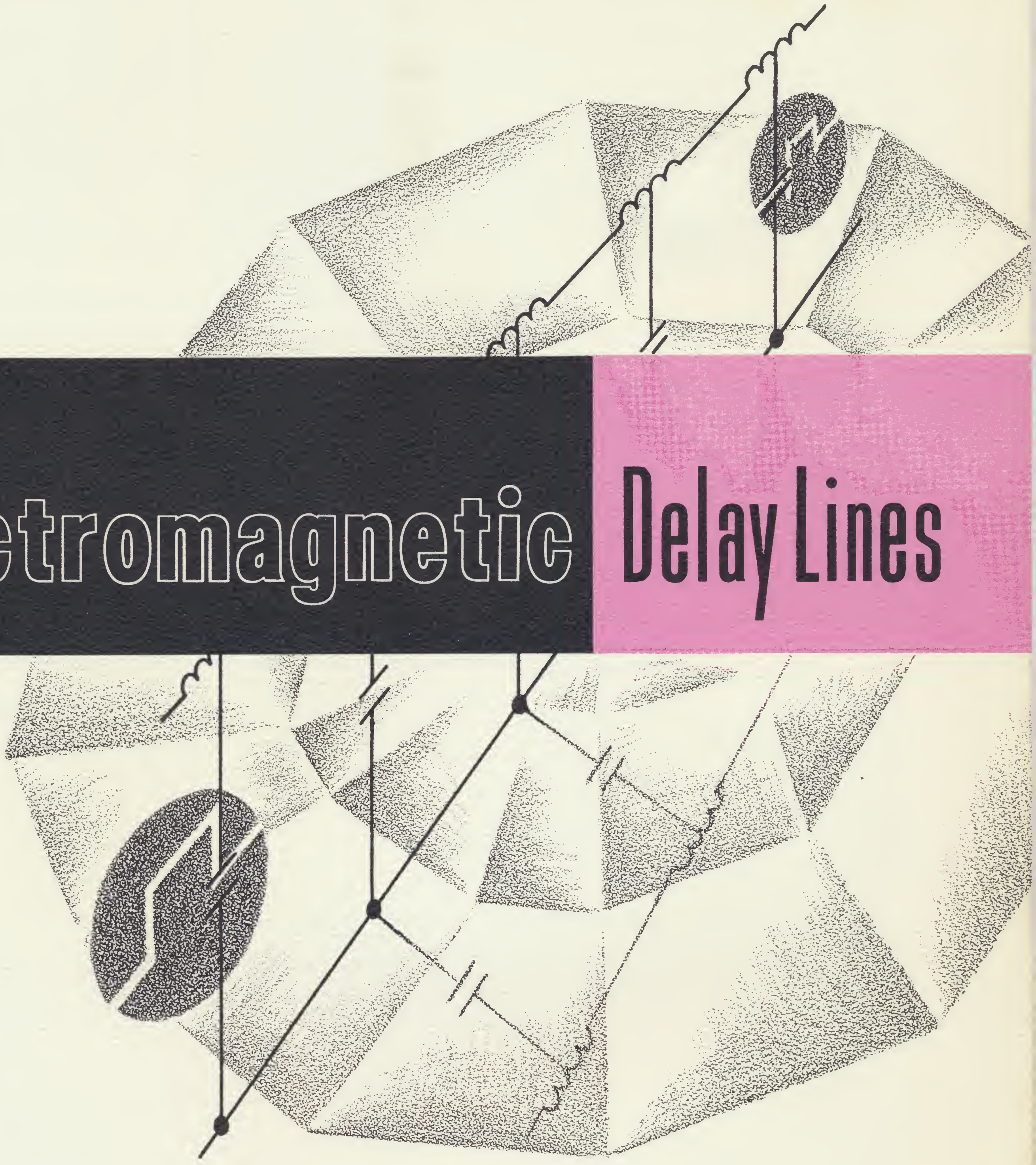
# Electromagnetic Delay Lines



ADVANCED COMPONENTS

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BOSTON, MASSACHUSETTS

# Introduction

Electromagnetic delay lines are passive filter networks comprised of capacitive and inductive elements with properties such that a signal impressed upon the input will issue from the output after a specific time interval, the magnitude of which is a function of the L and C components of the line. Since in practice the elements of a delay line are not ideal, the signal undergoes attenuation and distortion as it passes through the line.

While a delay line may be of any one of the various types of filters — low-pass, bandpass, or high-pass — most commonly used delay lines are of the low-pass, ladder type. These in turn are divided into two major categories: lumped-parameter and distributed-parameter networks. In the former, the inductive and capacitive elements are discrete, separate components. In the latter, a single element — generally a solenoid wound over a conductive core — combines the desired properties of inductance and capacitance. In general, lumped-parameter delay lines are superior to distributed-parameter networks with respect to most characteristics, such as the maximum achievable quality factor (delay-to-rise time ratio); attenuation; delay and impedance range; and size and packaging flexibility. Distributed-parameter delay lines normally exhibit excellent spurious response, and are quite attractive in many applications because of their low cost. Among their chief disadvantages are their high attenuation, their poor temperature stability, and their restrictive form factor.

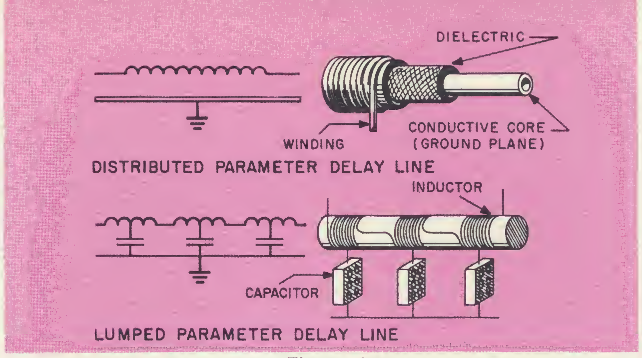

Figure 1A

The following paragraphs, covering definitions and measurements for electromagnetic delay lines, apply equally to both types.

## DEFINITIONS FOR ELECTROMAGNETIC DELAY LINES

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### 3. DEFINITIONS AND SYMBOLS

**3.1 Distortion** — May be defined specifically as a special case or more commonly as a generalized or all encompassing condition.

**3.1.1 Specific** — Defined in % by specifically indicating the maximum value of pre-pulse distortion (b), pulse amplitude distortion (c), and post pulse distortion (d) relative to the pulse amplitude (E), where each is not necessarily of equally permissible amplitude. May further be defined by indicating the period in which these spurious responses may occur.

3.1.1.1 PRE-PULSE DISTORTION .......................................................b (%)

$$b\,(\%) = \pm \frac{|b|}{E} \times 100$$

where |b| represents **peak** pre-pulse distortion.

3.1.1.2 PULSE AMPLITUDE DISTORTION ..........................................c (%)

$$c\,(\%) = \pm \frac{|c|}{E} \times 100$$

where |c| represents **peak** pulse amplitude distortion.

3.1.1.3 POST PULSE DISTORTION .....................................................d (%)

$$d\,(\%) = \pm \frac{|d|}{E} \times 100$$

where |d| represents **peak** post pulse distortion.

**3.1.2 All Encompassing** ....................................................................S (%)
Defined as the largest peak amplitude of all spurious responses either in the positive or negative direction relative to the pulse amplitude. Calculated in %.

$$S\,(\%) = \pm \frac{|b| \text{ or } |c| \text{ or } |d|}{E} \times 100$$

where |b|, |c| or |d| represents largest **peak** amplitudes.

**3.2 Impedance**

**3.2.1 Characteristic Impedance** .............................................................$Z_o$
That value of terminating impedance which provides minimum reflections to the input of the line.

**3.2.2 Source Impedance** .........................................................................$Z_s$
The impedance of the pulse source as seen by the delay line input terminals.

**3.2.3 Terminating Impedance** ...................................................................Z
The impedance of the load as seen by the delay line output terminals.

**3.3 Pulse Amplitude** (see figures) ...........................................................E

**3.4 Temperature Coefficient of Delay** .....................................................$T_c$
The change in delay with temperature expressed as:

3.4.1 Parts per million per degree centigrade .......................(PPM/°C)
or,
3.4.2 Microsecond per microsecond per degree centigrade ($\mu$sec/$\mu$sec/°C)
or,
3.4.3 Percent per degree centigrade ...........................................(%/°C)

**3.5 Tilt** ...................................................................................................h
Expressed in % as: ..........................................................................h (%)

$$h\,(\%) = \pm \frac{|h|}{E} \times 100$$

where |h| is absolute value of height of tilt axis.

**3.6 Time**

**3.6.1 Delay Line Fall Time** ......................................................................$t_f$
The time of the amplitude decreasing edge of the output pulse, assuming a step-function input.

**3.6.2 Delay Line Rise Time** ......................................................................$t_r$
The time of the amplitude increasing edge of the output pulse, assuming a step-fůnction input.

**3.6.3 Delay Time** .....................................................................................$t_d$
Elapsed time between the 50% amplitude of the leading edges (refer to point 1 on all figures) of the delay line input and output pulses or between an otherwise designated input and output point.

**3.6.4 Pulse Duration** (see figures) ..........................................................t
**3.6.5 Pulse Fall Time** (see figures) .........................................................$t_{fn}$
**3.6.6 Pulse Rise Time** (see figures) .........................................................$t_{rn}$
**3.7 Voltage Attenuation** ...........................................................................$\alpha$
The difference in voltage amplitude between delay line input and output pulses or between an otherwise designated input ($E_{ni}$) and output ($E_{no}$). Expressed in % or db as:

3.7.1 $\alpha\,(\%) = \frac{Ei - Eo}{Ei} \times 100$ ..........................................................(%)

3.7.2 $\alpha\,(\text{db}) = 20 \log_{10} \frac{Ei}{Eo}$ ..........................................................(db)

3.7.3 $\quad = 20 \log_{10} \frac{Eni}{Eno}$ ..........................................................(db)

### 4. NOTES

**4.1 Figure 1** — General case.
**4.2 Figure 2** — Where tilt is essentially 0 (zero), the axis of oscillation will be horizontal, eliminating the need of establishing intersection points 2 and 3 of Figure 1.
**4.3 Figure 3** — Where pulse width is narrowed to the point where no axis of oscillation ($A_p$) can be established then the pulse amplitude (E) will be considered as the peak of the pulse.

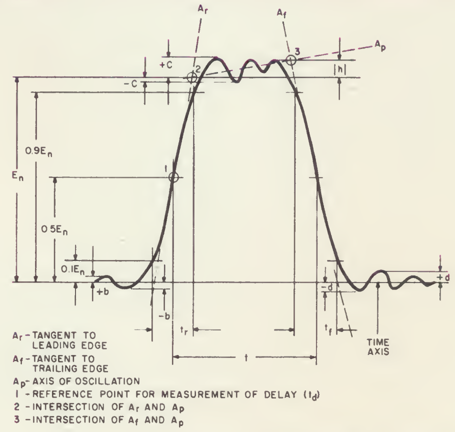


Figure 1 *GENERAL CASE*

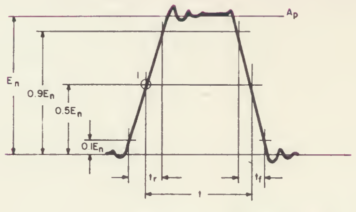


Figure 2 *SPECIAL CASE I*

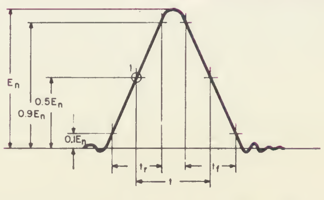


Figure 3 *SPECIAL CASE II*

## STANDARD LUMPED — PARAMETER DELAY LINES

Delay Tolerance: ±5%

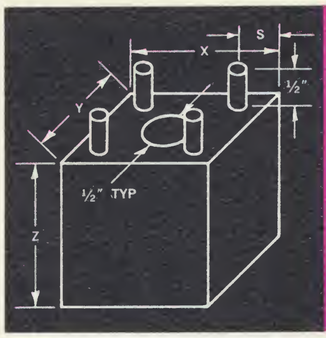
Attenuation:
- 1 μsec and below: 1 db max.
- 1 μsec — 10 μsec: 3 db max.
- 10 μsec — 25 μsec: 5 db max.

Temperature Coefficient of Delay: 50 ppm /°C. max.

Operating Temperature Range: −55°C. to 125°C.

Construction: Hermetically sealed in steel case

Finish: Grey lacquer over hot tin dip or copperplate




| Case Letter | X | Y | Z | S | # Studs | Stud Thread |
|---|---|---|---|---|---|---|
| A | 1½" | 1½" | 3" | ¼ | 2 | 6-32 |
| B | 2" | 2" | 4" | ¼ | 4 | 6-32 |
| C | 2" | 4" | 4" | ⅜ | 4 | 8-32 |
| D | 4" | 4" | 4" | ⅜ | 4 | 8-32 |

| | | LFE MODEL NUMBER | | | |
|---|---|---|---|---|---|
| | | CHARACTERISTIC IMPEDANCE | | | |
| DELAY TIME | RISE TIME | 50 Ω | 100 Ω | 500 Ω | 1000 Ω |
| .25 μsec | .015 μsec<br>.025 μsec | 0050–0.25–.015A<br>0050–0.25–.025A | 0100–0.25–.015A<br>0100–0.25–.025A | 0500–0.25–.015A<br>0500–0.25–.025A | 1000–0.25–.015A<br>1000–0.25–.025A |
| .50 μsec | .03 μsec<br>.05 μsec | 0050–0.50–0.03A<br>0050–0.50–0.05A | 0100–0.50–0.03A<br>0100–0.50–0.05A | 0500–0.50–0.03A<br>0500–0.50–0.05A | 1000–0.50–0.03A<br>1000–0.50–0.05A |
| 1.0 μsec | .03 μsec<br>.05 μsec<br>.10 μsec | 0050–1.00–0.03B<br>0050–1.00–0.05A<br>0050–1.00–0.10A | 0100–1.00–0.03B<br>0100–1.00–0.05A<br>0100–1.00–0.10A | 0500–1.00–0.03B<br>0500–1.00–0.05A<br>0500–1.00–0.10A | 1000–1.00–0.03B<br>1000–1.00–0.05A<br>1000–1.00–0.10A |
| 5.0 μsec | .15 μsec<br>.25 μsec<br>.50 μsec | 0050–5.00–0.15C<br>0050–5.00–0.25B<br>0050–5.00–0.50A | 0100–5.00–0.15C<br>0100–5.00–0.25B<br>0100–5.00–0.50A | 0500–5.00–0.15C<br>0500–5.00–0.25B<br>0500–5.00–0.50A | 1000–5.00–0.15C<br>1000–5.00–0.25B<br>1000–5.00–0.50A |
| 10.0 μsec | .30 μsec<br>.50 μsec<br>1.0 μsec | 0050–10.0–0.30C<br>0050–10.0–0.50C<br>0050–10.0–1.00B | 0100–10.0–0.30C<br>0100–10.0–0.50C<br>0100–10.0–1.00B | 0500–10.0–0.30C<br>0500–10.0–0.50C<br>0500–10.0–1.00B | 1000–10.0–0.30C<br>1000–10.0–0.50C<br>1000–10.0–1.00B |
| 25.0 μsec | .5 μsec<br>1.0 μsec<br>2.5 μsec | 0050–25.0–0.50D<br>0050–25.0–1.00C<br>0050–25.0–2.50B | 0100–25.0–0.50D<br>0100–25.0–1.00C<br>0100–25.0–2.50B | 0500–25.0–0.50D<br>0500–25.0–1.00C<br>0500–25.0–2.50B | 1000–25.0–0.50D<br>1000–25.0–1.00C<br>1000–25.0–2.50B |

Letters following model numbers refer to case sizes as given in table above

## STANDARD DISTRIBUTED — PARAMETER DELAY LINES

Delay Tolerance: ±5%

**Attenuation: 1 db/μsec (approx.)**

Temperature Coefficient of Delay: 70 PPM/°C. max.

Operating Temperature Range: −55°C. to +125°C.

Construction: Epoxy-encapsulated in ⅜" O.D. epoxy or phenolic tube; pigtail leads 6" long

Length:
- up to 0.3 μsec — 2"
- 0.3 μsec to 0.5 μsec — 4"
- 0.5 μsec to 1 μsec — 6"

| | | LFE MODEL NUMBER | | | |
|---|---|---|---|---|---|
| | | CHARACTERISTIC IMPEDANCE | | | |
| DELAY TIME | RISE TIME | 500 Ω | 1000 Ω | 1500 Ω | 2000 Ω |
| .05 μsec | .01 μsec | 0500–0.05DP | 1000–0.05DP | 1500–0.05DP | 2000–0.05DP |
| .10 μsec | .015 μsec | 0500–0.10DP | 1000–0.10DP | 1500–0.10DP | 2000–0.10DP |
| .20 μsec | .03 μsec | 0500–0.20DP | 1000–0.20DP | 1500–0.20DP | 2000–0.20DP |
| .30 μsec | .04 μsec | 0500–0.30DP | 1000–0.30DP | 1500–0.30DP | 2000–0.30DP |
| .40 μsec | .06 μsec | 0500–0.40DP | 1000–0.40DP | 1500–0.40DP | 2000–0.40DP |
| .50 μsec | .07 μsec | 0500–0.50DP | 1000–0.50DP | 1500–0.50DP | 2000–0.50DP |
| .60 μsec | .08 μsec | 0500–0.60DP | 1000–0.60DP | 1500–0.60DP | 2000–0.60DP |
| .70 μsec | .10 μsec | 0500–0.70DP | 1000–0.70DP | 1500–0.70DP | 2000–0.70DP |
| .80 μsec | .12 μsec | 0500–0.80DP | 1000–0.80DP | 1500–0.80DP | 2000–0.80DP |
| .90 μsec | .13 μsec | 0500–0.90DP | 1000–0.90DP | 1500–0.90DP | 2000–0.90DP |
| 1.00 μsec | .14 μsec | 0500–1.00DP | 1000–1.00DP | 1500–1.00DP | 2000–1.00DP |

The delay lines on this list are intended to meet the majority of prototype requirements with fast delivery and at low cost. However, they do not represent the limits of the state-of-the-art, nor are they intended as substitutes for custom networks designed to specific requirements.

## MEASUREMENTS

A basic pulse delay line measurement set-up is shown in Figure 4. The delay is measured by counting the number of time markers between input and output signals; these time markers may be fed either into one of the vertical amplifiers or into the Z-axis modulation terminals of the oscilloscope. The output rise time of the pulse generator should be no more than 1/10 of the delay line rise time; the bandwidth of the oscilloscope should be at least five times that of the delay line. Low capacity probes should be used to reduce loading of the network.

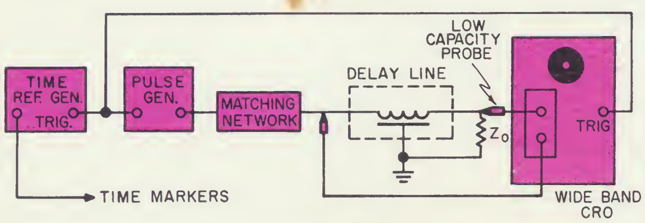



Figure 4.

## APPLICATIONS

Electromagnetic delay lines have found wide application in all fields of electronics — as storage and pulse shaping devices; in auto-correlation and phasing systems; in coincidence and discriminator circuits; in encoders and decoders; etc. The figures shown illustrate some typical applications.

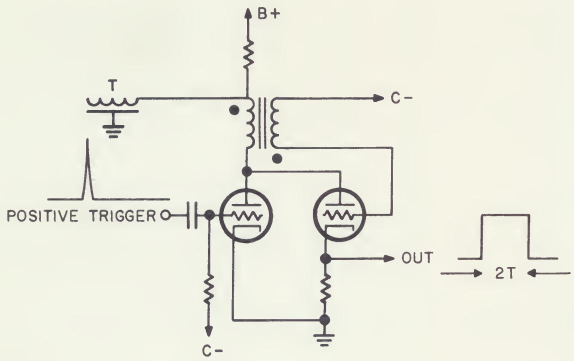



Figure 5. Delay Line-Controlled Blocking Oscillator

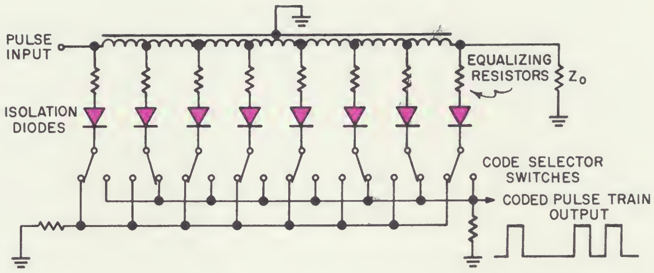



Figure 6. Serial Pulse Position Encoder

## SPECIFYING ELECTROMAGNETIC DELAY LINES

Specifications should include the following:

1. Delay and tolerance
2. Maximum output rise time
3. Maximum attenuation
4. Characteristic impedance
5. Maximum allowable distortion
6. Maximum pulse input level
7. Insulation resistance and hipot level
8. Maximum temperature coefficient
9. Physical size; package, terminal, and mounting requirements
10. Environmental requirements

A general description of the application, with schematics of the driving circuitry and illustration of input waveform characteristics, is highly desirable. Consultation with our experienced delay line engineers before a design is frozen will result in great benefits to the buyer with respect to both cost and reliability.

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A DIVISION OF LABORATORY FOR ELECTRONICS, INC.

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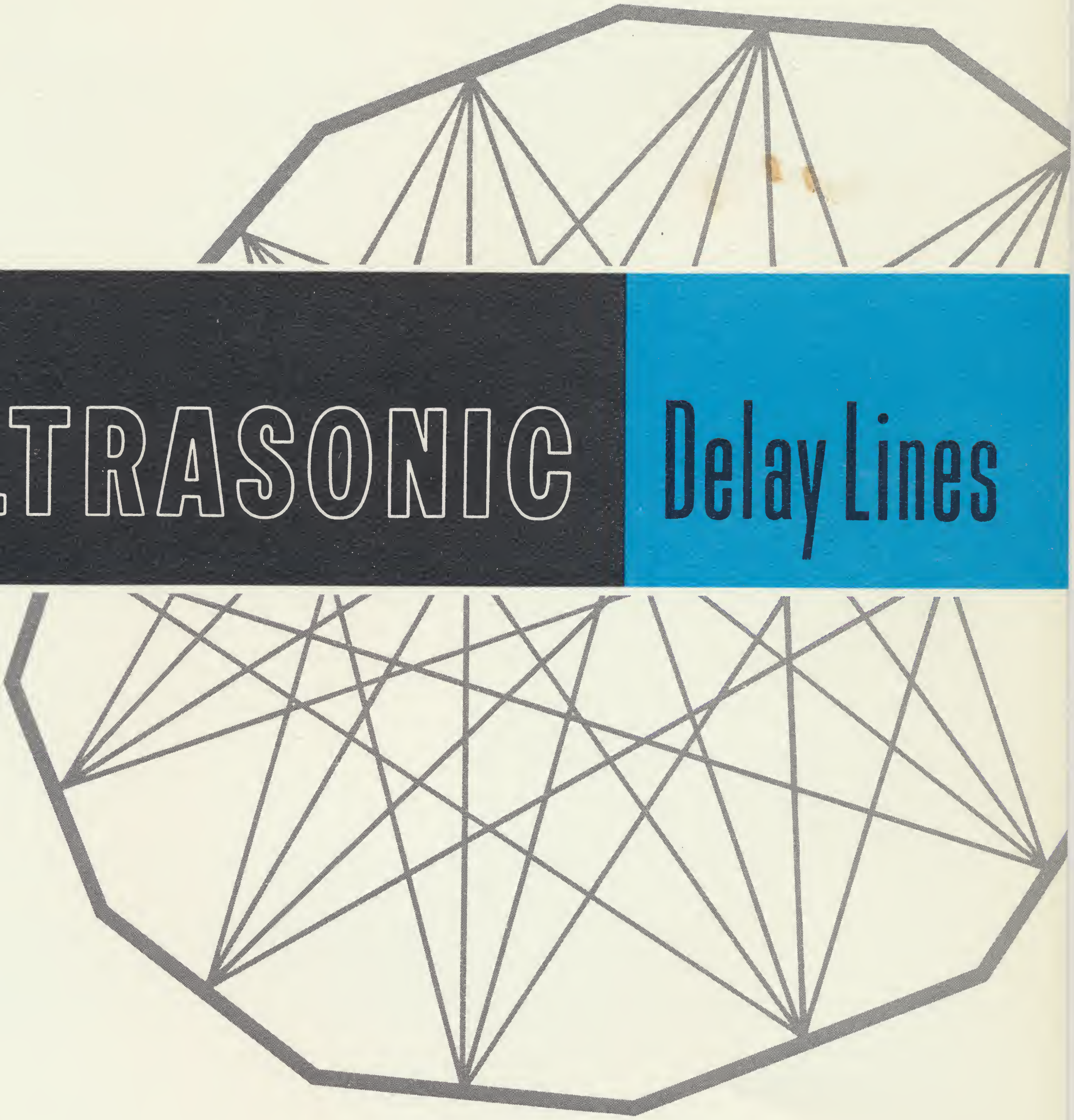
Delay Lines • Filters • Transformers • Memory Systems
Bernoulli Disks • Temperature Controllers • and Related Electronics

# ULTRASONIC Delay Lines



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BOSTON, MASSACHUSETTS

# Solid Ultrason

## Ultrasonic Delay Lines

Advances in radar technology have created a need for stable, reliable, wideband devices capable of achieving long delays with little distortion. Such devices are needed in MTI and distance measuring equipment, video integrators, and similar systems. Most of the necessary requirements can be fulfilled by ultrasonic delay lines, which make use of the slow velocities of acoustic waves through liquid or solid media to achieve long delays in relatively little space.

A typical ultrasonic delay line consists of an input transducer affixed to, or in contact with, the delay medium (see Figure 1). An electrical signal impressed upon this transducer (ordinarily a piezoelectric crystal or ceramic) is converted into an acoustic wave which is propagated through the

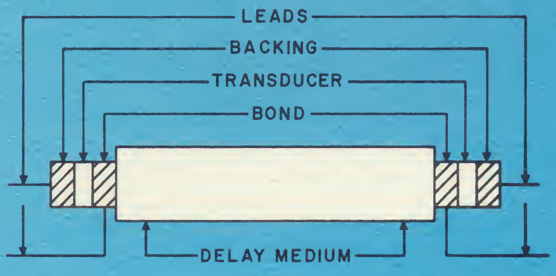



**Figure 1.** Ultrasonic Delay Line

medium with a velocity characteristic of that particular medium. Upon reaching the output transducer the acoustic signal is reconverted into a replica of the original electrical signal, delayed by a time interval equal to the propagation time through the delay medium. Of course, while it traverses the delay line, the signal undergoes attenuation and some distortion. While a great many delay media including water, mercury, nickel, and magnesium have been tried out over the years, present designs employ fused quartz almost exclusively: the use of metals is generally limited to aluminum and certain constant-modulus nickel alloys.

## MATERIALS

Fused quartz, or vitreous silica, combines excellent loss properties over a wide frequency range with good handling and manufacturing characteristics, and provides a good impedance match with commonly used transducer materials. Like all solids, it can sustain both of the major modes of propagation of ultrasonic waves: the longitudinal, or compressional mode, in which the particle motion is in the same direction as the wave motion; and the shear mode, in which the particle motion is perpendicular to the direction of travel of the acoustic wave. The former mode is generated by X-cut quartz crystals, and in fused quartz travels with a velocity of approximately 4.26 microseconds per inch; shear waves are generated by Y-cut or AC-cut crystals, and travel with a velocity of approximately 6.75 microseconds per inch. Both types of waves can be generated by suitably polarized piezoelectric ceramics such as barium titanate and lead zirconate titanate (PZT). Because of the high temperature coefficient of quartz (−70 to −80 ppm/°C for shear waves, −100 ppm/°C for compressional waves), close control of the delay requires that the delay line be packaged in an isothermal enclosure which is generally maintained above the maximum ambient temperature of the device. Added benefits of high temperature operation are an increase in bandwidth and a decrease in attenuation.

To eliminate the restrictions imposed by the high temperature coefficient of delay of quartz, various glass compositions exhibiting low temperature coefficients have been developed. The delay stability of the zero-temperature coefficient glass used by LFE is illustrated in Figure 2. Acoustic losses are somewhat greater than in fused quartz, so that the use of zero-temperature-coefficient glass is limited to applications requiring delays under 300 microseconds; however, this disadvantage is more than offset by the better bandwidth and spurious characteristics achievable with glass.

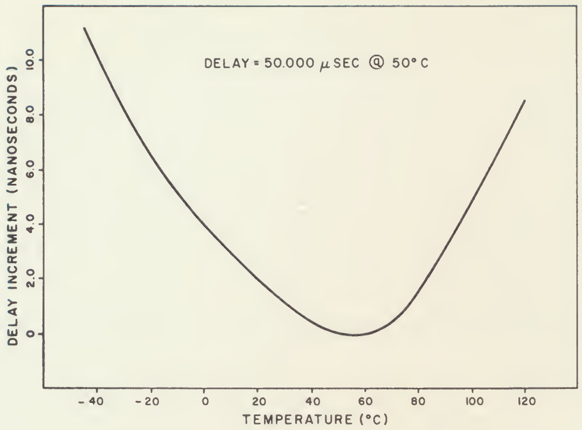



**Figure 2.** Delay vs. Temperature Characteristics — Zero-Temperature-Coefficient Glass Delay Lines

# ic Delay Lines . . .

## CONFIGURATIONS

It is obvious that for long path lengths a straight bar configuration would be both impractical and costly; hence, for long delays the beam path is folded, and the ultrasonic beam is reflected from plane facets machined on the delay line blank (Figure3). In such lines the thickness shear mode (with particle motion perpendicular to the major faces of the blank) is generally used to take advantage of the slower acoustic velocity per unit length, and to reduce spurious signals. To a great extent the limits of the state-of-the-art are set by the compromise between compactness of the delay line blank (or in other words, by the number of folds in the delay path) and the achievable minimum spurious signal level; at LFE, polygon configurations are optimized with the aid of a high speed digital computer. New patterns are constantly being devised, and nearly two hundred are presently filed. Long delays are available (up to 6000 microseconds in a single 18-inch blank), and of course longer delay times may be obtained by combination. A number of novel configurations — including a patented three-dimensional path device — have been developed in this laboratory.

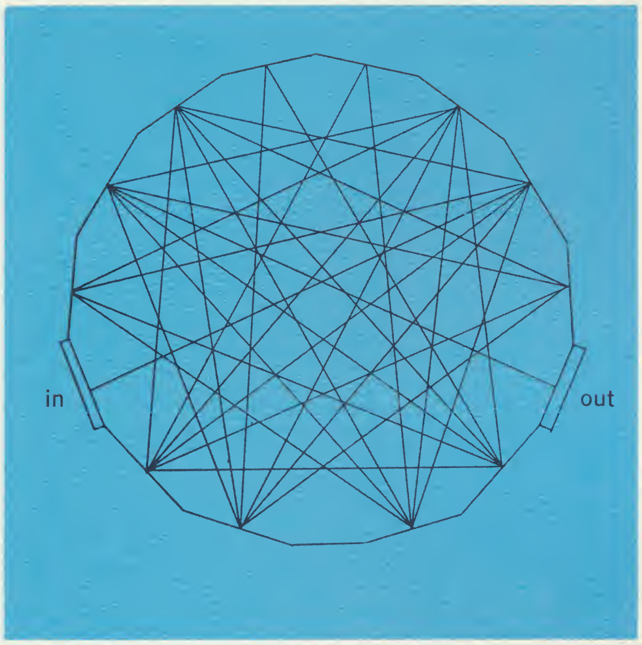



**Figure 3.** Typical Folded Path Configuration — 15MS31

## TRANSDUCERS

A critical step in the manufacture of solid ultrasonic delay lines is the design of the transducer assembly. Various proprietary methods have been evolved to ensure good impedance match between the transducer and the solid medium so as to achieve maximum signal transfer with minimum spurious signals and distortion. These electrical features must be coupled with stable mechanical characteristics to permit operation over environmental extremes. To prevent unwanted echoes from the transducer-air interface, and to increase bandwidth, an acoustic absorber is mounted behind each transducer; the proper selection and configuration of these absorbers are important considerations in the design of a specific delay line.

Since the transducers are resonant devices, a solid ultrasonic delay line behaves like a bandpass filter with a frequency of minimum attenuation near the resonant frequency of the transducers. To derive maximum benefit from this property, the signal to be delayed or stored is generally used to modulate an RF carrier whose frequency is in the vicinity of the center frequency of the delay line; the delayed, modulated RF signal is detected to recover the original information (see figure 4). It is also possible to operate ultrasonic delay lines with RF carrier frequencies which are odd harmonics of the center frequency. Fundamental carrier frequencies range from 500 Kc to over 100 Mc; the use of harmonic carriers permits operation up to 500 Mc.

Under certain conditions it is possible to delay unmodulated signals; delay lines designed for this purpose are described in our Digital Delay Line brochure.

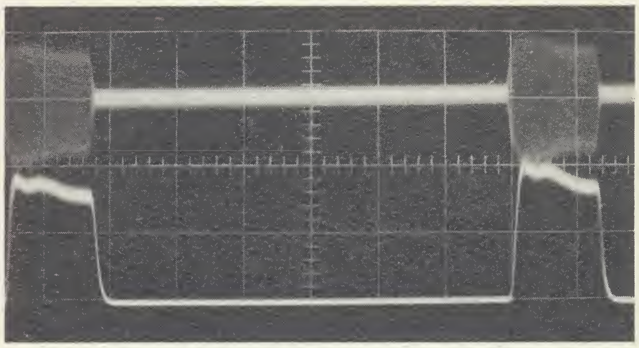


**Figure 4.** Typical Ultrasonic Delay Line Waveforms. Upper Trace: Undelayed Modulated RF Signal. Lower Trace: Delayed, Detected Signal

## TRANSDUCER EQUIVALENT CIRCUIT

A simplified equivalent circuit of a solid delay line transducer is shown in Figure 5. $L_O$ is an external inductor designed to resonate with $C_O$, the shunt capacitance of the transducer, at the delay line center frequency. $L_I$ and $C_C$ are the equivalent series mechanical reactances of the transducer and correspond to inertia and compliance, respectively. $R_A$ is the so-called radiation resistance and may be regarded as the characteristic impedance of the line; $R_L$ is the load resistance of the transducer.

Values of $C_O$ ordinarily range from 5 to 200 picofarads for quartz crystal transducers, and up to several thousand picofarads for ceramic transducers. Typical values of $R_A$ for quartz transducers range from 1000 ohms to about 10,000 ohms; for ceramic transducers $R_A$ values may be as low as 5 ohms.

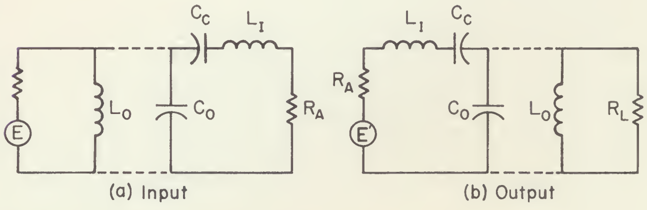



**Figure 5.** Delay Line Transducer Equivalent Circuit

## DEFINITIONS

In order to assist the user in setting up specifications and test methods for ultrasonic delay lines, the following definitions of important parameters are provided.

### Carrier Frequency

The RF carrier which is modulated by the information to be delayed, and which may or may not coincide with the peak frequency of the delay line.

### Time Delay

The time interval between input and output information, generally the measured interval between the input signal and the delayed output signal.

### Bandwidth

**a) Acoustic Bandwidth** — The acoustic bandwidth defines the basic performance characteristics of the line without the effects introduced by extraneous circuit elements. It is generally measured by resonating the transducers at each frequency with an inductor and taking the half power (3 db) points of the resulting response curve, or reading with low resistance loads.

**b) Electrical Bandwidth** — This is an operational term which describes the performance of a delay line under actual operating conditions. It is the 3 db bandwidth of the delay line terminated in the exact manner in which it will be used in the circuit; in this case the transducer capacity and its effect on the total circuit must be considered. Clearly the electrical bandwidth can never be quite as wide as the acoustic bandwidth without external compensation. The differences in acoustic and electrical bandwidths for a typical ultrasonic delay line are illustrated in Figure 6.

### Spurious Signals

Undesired signals which appear at the delay line output may originate from any of a variety of causes; maximum permissible levels (peak values) for each type are generally specified separately. Types of spurious signals are:

**a) Feedthrough** — This type of spurious signal is caused by capacitive coupling between input and output terminals, resulting in the appearance of undelayed noise. Such parasitic signals can be suppressed by careful terminal placement and good shielding, both during manufacture and during installation.

**b) Triple Travel** — This type of spurious signal occurs after a time interval equal to three times the line delay; it is due to acoustic mismatch at the transducers permitting part of the output signal to be reflected back to the input transducer, and back again to the output. These undesirable signals are minimized by proper transducer and backing design.

**c) Random Spurious Signals** — Other types of spurious signals are caused by beam spreading or diffraction, mode conversion, and non-homogeneity of the delay medium. These signals are minimized by selecting the optimum configuration; by judicious placement of acoustic corner absorbers; by proper selection of transducer geometry; by close control of angular tolerance; and by selection and grading of the delay line blanks.

### Attenuation

Attenuation or insertion loss in an ultrasonic delay line is the comparison of output voltage to input voltage under specified load conditions. In a short quartz delay line most of the signal loss is due to the transducers, the medium itself being essentially absorption-free. In glass delay lines, or in long quartz lines, the medium contributes substantially to the overall loss.

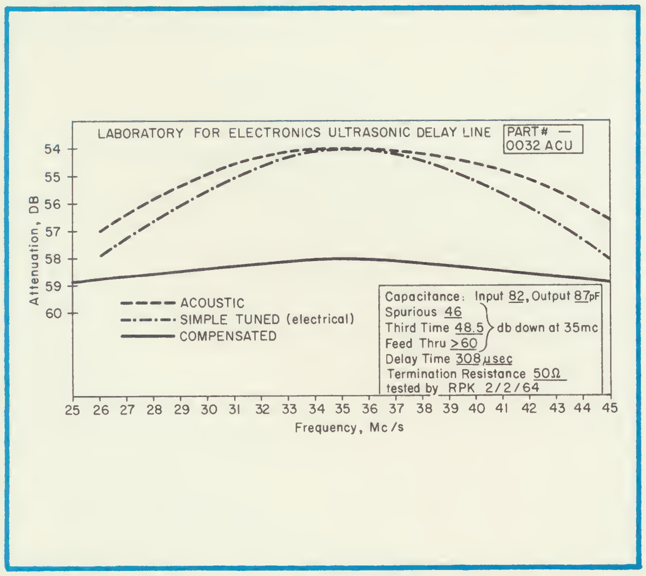



**Figure 6.** Acoustic and Electrical Bandwidth Characteristics

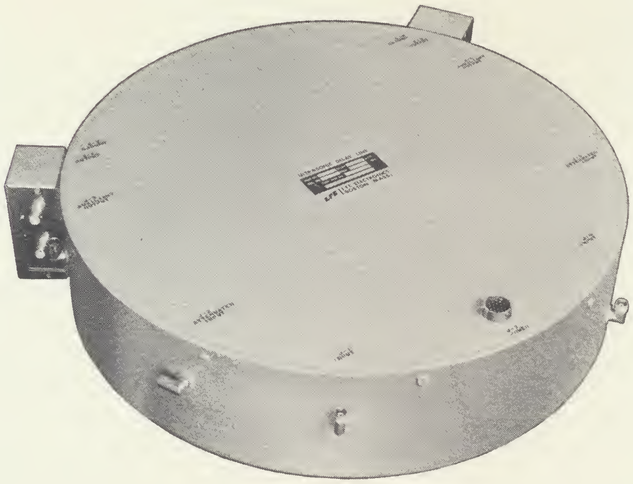


**Figure 7.** Four-channel Heated Delay Line
Delay per Channel: 3300 $\mu$sec, Center Frequency: 30 Mc
Application: MTI System

# Delay Lines . . .

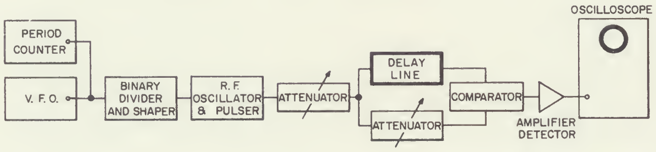
## MEASUREMENTS

Basic ultrasonic delay line measurement set-ups are presented in Figure 8. Attenuation measurements are made by a comparison method, with a variable attenuator substituted for the delay line. Spurious ratio is found by lowering the input level with the series attenuator until the delayed signal is at the spurious level. Bandwidth measurements are carried out by sweeping the RF oscillator over the desired frequency range and recording output levels at each frequency; or by using the set-up shown in Figure 8b.

Delay measurements may be carried out in two ways:

a) If the pulse repetition rate is fixed, the delay between input and output pulses may be compared against a time standard.

b) If the PRF is adjustable, it is varied until input and output pulses coincide; the delay is then some integral function of the driving PRF.




a) Pulsed RF Set-up

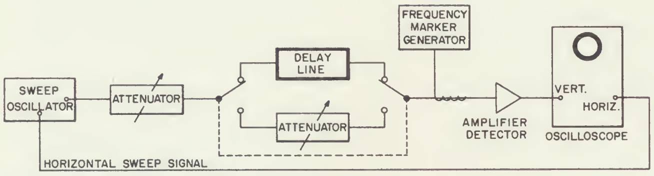



**Figure 8.** Delay Line Test Circuits b) Sweep Set-up

## ECHO LINES

A special class of ultrasonic delay lines is used to generate trains of pulses separated by equal and precise time intervals. Such lines — known as echo lines or rangemarkers — generally consist of a straight fused or crystalline quartz bar, either with a single transducer, or with a transducer at each end.

In the so-called single-ended echo line, an impulse fed into the transducer is reflected back and forth between the two ends of the bar. Each time the acoustic signal impinges upon the transducer an electrical signal is generated; the pulse spacing is therefore twice the propagation time through the bar. In the double-ended type, the first pulse occurs after the input pulse has traversed the bar once; the spacing between subsequent pulses is again twice the propagation time through the bar. To reduce absorption of the echoes the transducer backing is generally left off. The typical pulse train generated by an echo line is illustrated in Figure 9. LFE has manufactured echo lines with center frequencies up to 425 Mc.

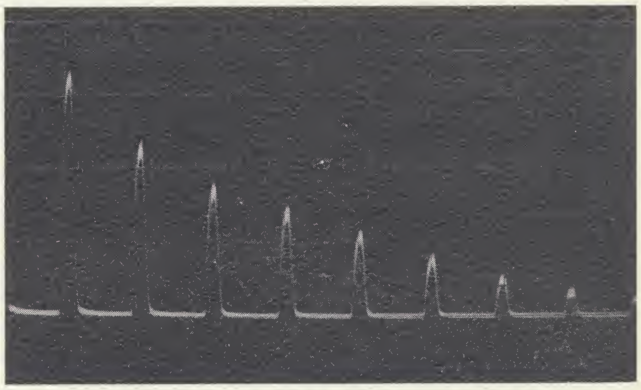


**Figure 9.** Echo Line Pulse Train

## CHARACTERISTICS OF TYPICAL LFE ULTRASONIC DELAY LINES

| LFE Part Number | Delay | Delay Medium | Center Frequency | Bandwidth | | Spurious | | | Attenuation | Transducer Capacity | Case Size |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Acoustic | Electrical | Feed-through | Triple Travel | Random | | | |
| 0023 ACU | 0.5-12.0 μs | 0 TC Glass | 30 Mc | 24 Mc min | 14 Mc into 75Ω | >60 db | >35 db | >60 db | 40 db into 75Ω | 60 pf | ¾" x ¾" x 1¼" |
| 0046 ACU | 50 μs | 0 TC Glass | 60 Mc | 35 Mc min | 20 Mc into 75Ω | >50 db | 45 db | >60 db | 54 db into 75Ω | 60 pf | 3½" x 2" x 1" |
| 100(3) | 2500 μs | Fused Quartz | 30 Mc | 18 Mc | 12 Mc into 75Ω | >60 db | >60 db | 55 db | 59 db into 75Ω | 65 pf | 14½" d x 1½" |
| 0032 ACU | 300 μs | Fused Quartz | 35 Mc | 12 Mc to −1 db points | 21 Mc to −1 db points * | >50 db | >50 db | 47 db | 58 db into 50Ω | 0‡ | 7" d x 1¼" |
| 57357 | 545 μs | Fused Quartz | 9 Mc | 3-4 Mc | 3.5 Mc into 100Ω | >60 db | 35 db | 44 db | 53 db into 100Ω | 35 pf | 5⅞" d x ¾" |
| 0020 ACU | 400 μs | Fused Quartz | 60 Mc | 35 Mc | 24 Mc into 50Ω | >60 db | 53 db | >60 db | 53 db into 50Ω | 90 pf | 6½" d x 1¼" |
| 0041 ACU | 83 μs | Fused Quartz | 75 Mc | >35 Mc | 16 Mc to −1 db points | 60 db | 53 db | >60 db | 50 db into 50Ω | 70 pf | 5¾" d x 2¾" |

*Electrically compensated at the transducers ‡Tuned out at 35 Mc


**Figure 10.** Tapped Glass Delay Line Package
Delay per Tap: 0.500 $\pm$0.010 $\mu$sec, Center Frequency: 30 Mc
Application: Coherent Radar System

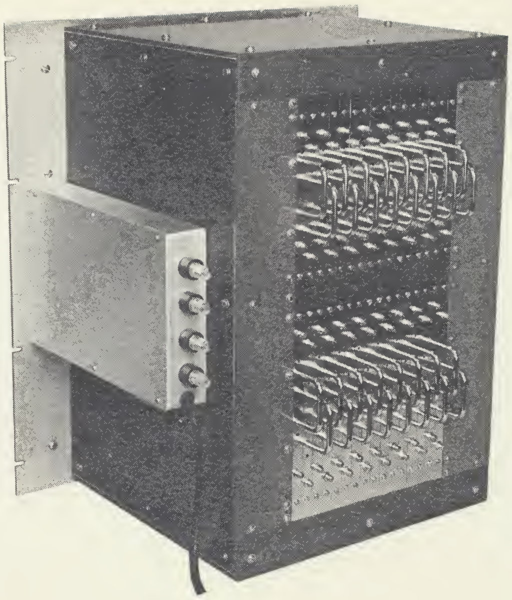


**Figure 11.** Modular Multidelay Package With Isothermal Enclosure.
No. of Delay Lines: 32, Delay Tolerance: $\pm$8 nanoseconds
Center Frequency: 60 Mc, Temperature Stability: 0.01°C
Application: Coherent Radar System

## SPECIFYING ULTRASONIC DELAY LINES

Since both electrical and mechanical requirements vary widely, ultrasonic delay lines can rarely be procured from stock. Specifications for custom-designed components should include the following information:

1. Total delay and tolerance
2. Nominal center frequency
3. Minimum allowable bandwidth
4. Maximum allowable attenuation
5. Maximum permissible spurious signal levels
6. Input and output impedances
7. Load resistance
8. Operating temperature range, and stability within that range. In the event that quartz is to be used as the delay medium, state power available for heaters, expected ambient levels, and allowable warm-up time.
9. Physical size, packaging, and type of connectors
10. Environmental requirements
11. A general description of the application, with schematics of driving, detecting and amplifying circuits, is desirable. Input signal characteristics should accompany the specifications.

Echo line specifications should include the following information:

1. Single or double-ended type
2. Input pulse width
3. Required number of echoes over a given time period, or pulse spacing
4. Echo decay rate

## SPECIAL UNITS

In addition to the conventional delay lines described above, LFE Electronics offers delay or memory packages for special requirements. These include:

- Tapped Delay Lines
- Stacked Delay Lines
- Variable Delay Lines
- Multiple-channel Delay Lines
- Isothermal Quartz Delay Line Packages Incorporating Heaters and Associated Control Circuitry
- Multipackages incorporating two or more delay lines
- Complete serial memory systems

Some representative designs are illustrated in the accompanying photographs.

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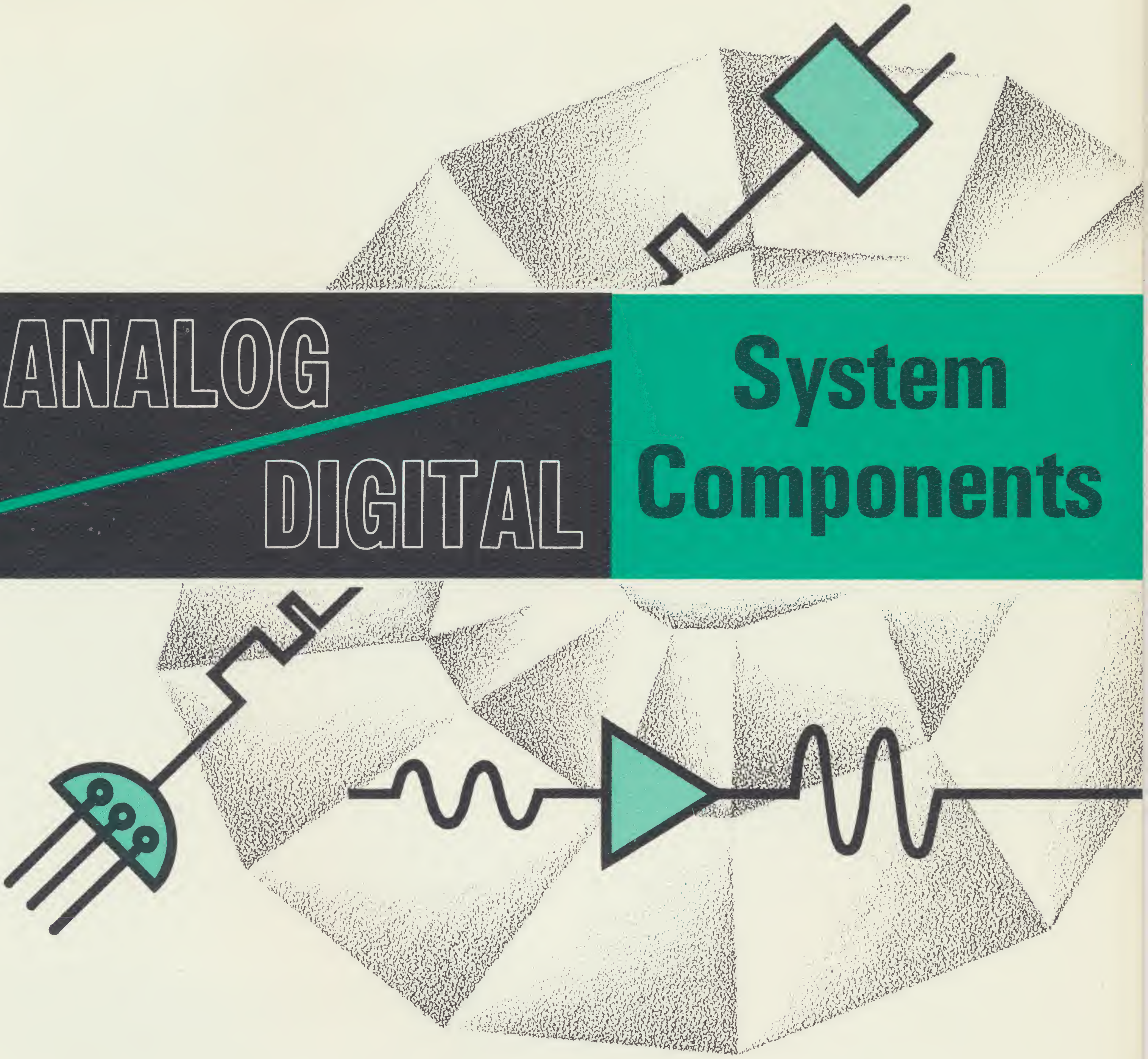
**Delay Lines • Filters • Transformers • Memory Systems**
**Bernoulli Disks • Temperature Controllers • and Related Electronics**

# ANALOG DIGITAL System Components



LFE

advanced components

## LFE ELECTRONICS

A DIVISION OF LABORATORY FOR ELECTRONICS, INC.

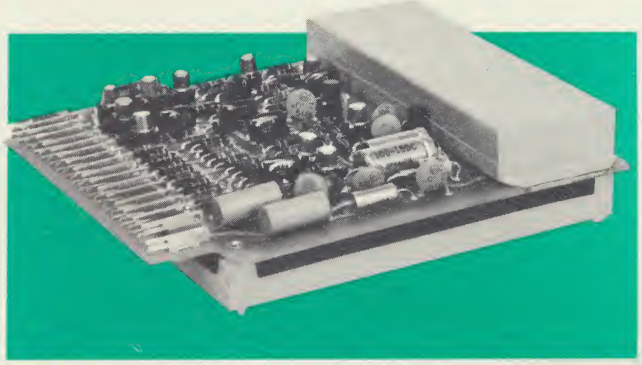
## SUM SERIES SERIAL ULTRASONIC MEMORIES

SUM Series memories are high-speed, self-contained units which add building-block flexibility to systems design. They are completely solid-state, and offer a wide range of combinations with regard to storage capacity and bit rate.

Electrically, the SUM consists of an ultrasonic-digital delay line complete with gating circuits, input shaper and driver, post delay amplifier, code detector and output flip-flop. Memories are available to accept and deliver RZ or NRZ code.

Functionally, the SUM is a shift register with length equal to the number of bits delayed by the delay line and shift rate determined by the master clock. Continuous storage may be obtained by returning the memory output to the input gating circuitry.

Units with delays of up to 150 microseconds consist of a plug-in glass epoxy printed circuit board which



supports the completely shielded delay line enclosure and the shielded electronic circuits.

In units with delays in excess of 150 microseconds, the electronic circuit card is mounted inside the delay line case.

### SPECIFICATIONS

| | |
|---|---|
| **Frequency Range** | 0.2 to 40 mc/s |
| **Storage Capacity** | in excess of 20,000 bits |
| **Delay Medium** | Digital ultrasonic delay line |
| **Operating Temperature range** | 0 to 50°C |
| **Delay adjustment** | ± one bit |
| **Clock stability** | 20-50 ppm depending on length of delay and clock frequency |
| **Input loading** | 8 ma each gate |
| **Output drive** | 12 ma |
| **Power required** | −12 vdc at 240ma<br>+ 6 vdc at 10ma |
| **Input/output levels** | 0 and −6 volts (positive input/outputs available on request) |

To determine system parameters this formula may be used:
Storage Capacity (in bits) = Clock Frequency (mc/s) x Pulse Delay ($\mu$secs)

## ANALOG DELAY SYSTEMS

LFE analog delay systems are stable, reliable, wideband IF pulse storage devices for MTI radars, distance measuring equipment, video integrators, and other advanced data analyzing applications. They are basically ultrasonic delay lines utilizing the slow velocities of acoustic waves in quartz or vitreous silicon to achieve the required delays.

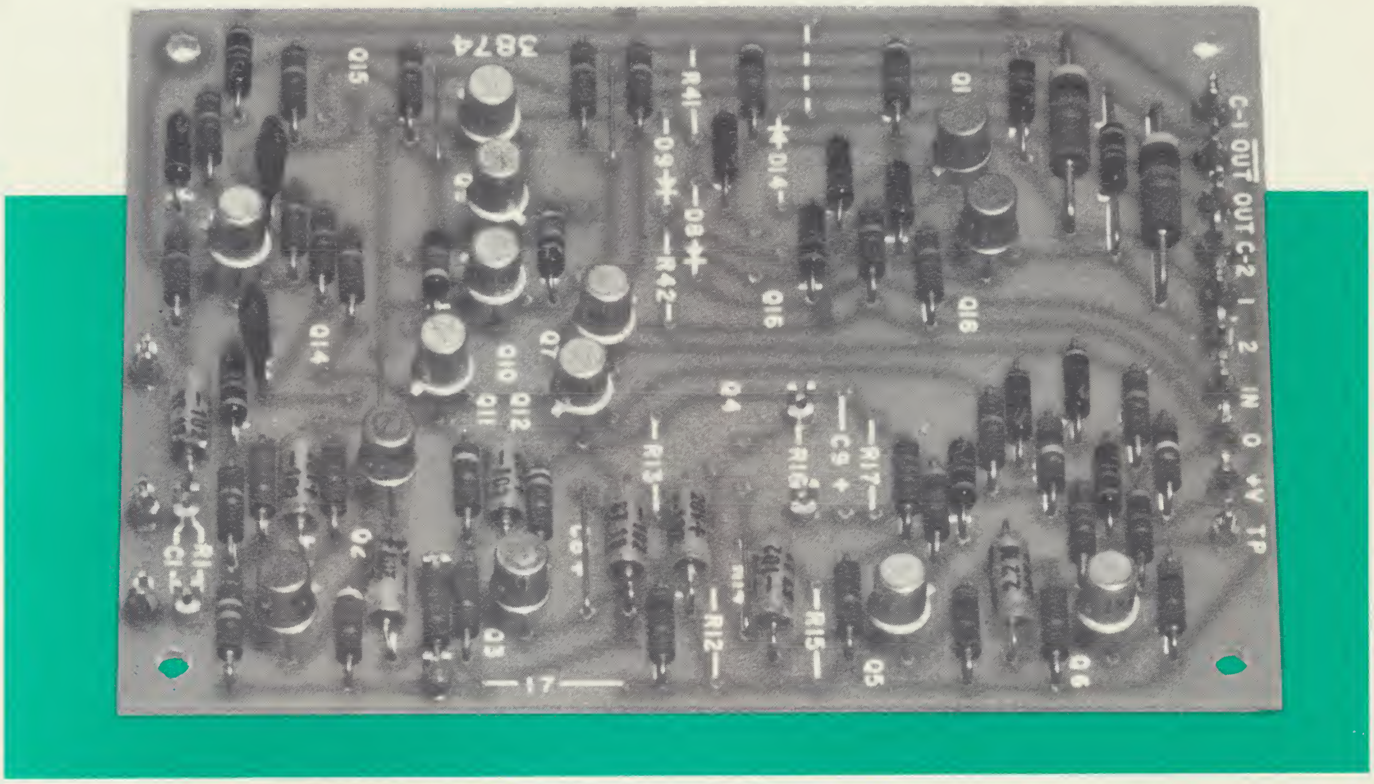
The ultrasonic delay line is a lossy device and requires a post amplifier to raise the delay line output to workable levels. By integrating the delay line and amplifier design, LFE relieves the user of intricate interface problems such as impedance matching for bandwidth preservation, and minimization of signal losses and external noise pickup.

Unity gain systems are standard. But others are available on request. Video and/or IF signal outputs are available with up to 10 watts drive capability. (Fifty-ohm loads are standard.)

Delays available range from 0.5 to 5,000 microseconds. Carrier frequencies range from 5 to 90 mc/s. Delay stability is assured by isothermal packaging of the delay medium. Active impedance-transformation networks are available for matching signal source to delay line input impedances.

# UNIVERSAL AMPLIFIERS

## for Digital Delay Lines



## DESCRIPTION

The DLA1015 is a universal amplifier series developed to meet all the requirements necessary to operate magnetostrictive delay lines digitally. The unit is available in both a commercial and military version, qualified to meet MIL Standard 701. The circuitry uses silicon diodes and transistors throughout and operates entirely with a +12VDC power supply.

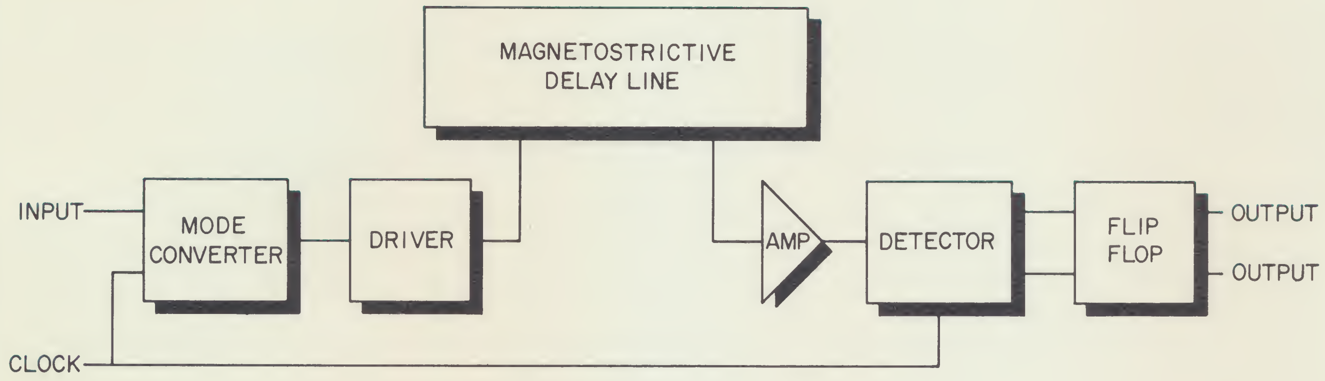
When the delay module is operated with negative polarity logic it is only required to add conversion stages to the input and output of the amplifier. These conversion cards are readily available to specific requirements along with any necessary input or output logic gates.

The DLA1015 series amplifier is designed to operate over the necessary gain-bandwidth conditions to be compatible with all magnetostrictive delay lines. The amplifier is supplied with both solder lugs and connectors and is easily attached to the delay line for ready installation in buffers, memory units, communications equipment, displays and other delay line applications.

## SPECIFICATIONS

| | |
|---|---|
| **Power** | +12 VDC ± 5% |
| **Input Levels** | "0" < 0.3v at 4ma<br>"1" > 1.0v less than 1ma |
| **Output Levels** | "0" < 0.3v 10ma<br>"1" > 1.0v less than 5$\mu$a |
| **Temperature** | Commercial 0° to 60°C<br>Military −54° to 100°C |
| **Environment** | MIL-E-16500B<br>MIL Std 701 |
| **Material** | Silicon transistors and diodes G-10 glass epoxy printed circuit board. |
| **Dimensions** | 3″ x 4″ x ½″ high over all<br>2⅝″ x 3⅝″ mounting centers |

## FUNCTION DIAGRAM




## OPERATING MODES

| MODEL | INPUT | | OUTPUT | | DELAY LINE | |
|---|---|---|---|---|---|---|
| No. | Mode | Clock | Mode | Clock | Mode | Max. Data Freq. |
| DLA1015-1 | NRZ | No | NRZ★ | No | NRZ | 2 Mc |
| DLA1015-2 | NRZ | No | NRZ★ | Yes | NRZ | 2 Mc |
| DLA1015-3 | NRZ | Yes | RZ | No | RZ | 1 Mc |
| DLA1015-4 | NRZ | Yes | NRZ★ | Yes | RZ | 1 Mc |
| DLA1015-5 | NRZ | Yes | NRZ★ | Yes | Bi-polar | 1 Mc |
| DLA1015-6 | NRZ | Yes | RZ★ | Yes | Bi-polar | 1 Mc |
| DLA1015-7 | RZ | No | RZ | No | RZ | 1 Mc |
| DLA1015-8 | RZ | No | RZ | Yes | RZ | 1 Mc |
| DLA1015-9 | RZ | Yes | RZ★ | Yes | Bi-polar | 1 Mc |
| DLA1015-10 | RZ | No | NRZ★ | Yes | RZ | 1 Mc |
| DLA1015-11 | RZ | Yes | NRZ★ | Yes | Bi-polar | 1 Mc |
| DLA1015-12 | Ternary RZ | Yes | Ternary RZ | Yes | Ternary | 1 Mc |

★The complement is also available

## WIDE BAND AMPLIFIERS

These amplifiers feature high gain, fast rise time, wide frequency range, low power requirements, and solid state circuitry. They are versatile and economical to purchase and use.

The AWB30/31/32 Series are intended for a wide range of applications in pulse preamplification, gain measurements, research in the VHF range, and voltmeter and oscilloscope range extension. Designed to stringent requirements, they feature fast rise times, low distortion, wide frequency range and linear dynamic range.

The AV20/40/60 Series are designed for use in digital memory systems using ultrasonic delay lines as memory elements. However, they can be used in a wide range of pulse, video, audio and high frequency applications where high signal reproduction quality and high output voltage are required. Outstanding features include transistorized circuits, wide band response, high gain and high output.


### SPECIFICATIONS

| Parameter | AWB30 | AWB31 | AWB32 | AV20 | AV40 | AV60 |
|---|---|---|---|---|---|---|
| Gain (db) | 20 | 40 | 60 | 60 | 60 | 60 |
| Bandwidth | 150 Kc to 130 Mc | | | 500 cps to 5 Mc | 500 cps to 10 Mc | 500 cps to 30 Mc |
| Input Impedance | 50Ω | | | 900Ω | 1000Ω | 1000Ω |
| Output Impedance | Matched for 50Ω load | | | 200Ω | 200Ω | 100Ω |
| Equivalent Input Noise | 20 μvolts | | | 5 μvolts | 7 μvolts | 10 μvolts |
| Output level | 0.35V rms | | | 1V rms | 1V rms | 0.8V rms |
| Delay Characteristics | 10 nanosecs | 20 nanosecs | 30 nanosecs | | | |
| Ambient | 0°C to +55°C | | | −50°C to +55°C | | |
| Connectors | BNC | | | | | |
| Power Required | 9 vdc 50 ma | 9 vdc 100 ma | 9 vdc 150 ma | +12 vdc at 30 ma | | |
| Size (inches) | 5⅝ x 2 x 1 | 6 x 4½ x 1 | 6 x 9 x 1 | 5⅝ x 2 x 1 | 6¾ x 2 x 1 | 7¾ x 2 x 1 |

## TRANSISTORIZED IF PREAMPLIFIERS

Standard units accept inputs from a 150Ω balanced mixer. Units for unbalanced input are available on request. These preamplifiers are compatible with LFE transistorized amplifiers, Series IF 100 to IF 104.

| Model | Center Frequency (Mc) | Band-width (Mc) | Power Gain (db) | Noise Figure (db) | Output Impedance (ohms) |
|---|---|---|---|---|---|
| IF 90 | 5 | 2 | 30 | 3.0 | 50 |
| IF 91 | 10 | 3 | 30 | 3.0 | 50 |
| IF 92 | 15 | 5 | 30 | 3.0 | 50 |
| IF 93 | 30 | 10 | 30 | 3.0 | 50 |
| IF 94 | 42 | 10 | 30 | 3.0 | 50 |
| IF 95 | 60 | 10 | 30 | 3.5 | 50 |
| IF 96 | 60 | 20 | 30 | 3.5 | 50 |
| IF 97 | 120 | 20 | 30 | 6.0 | 50 |

## TRANSISTORIZED IF AMPLIFIERS

A wide selection of bandwidth and center frequency combinations is available. Standard combinations are listed here. Other combinations are available on special order.

| Model | Center Freq. (Mc) | Band-width (Mc) | Gain (db) | Rise Time ($\mu$secs) |
|---|---|---|---|---|
| IF 100 | 20 | 2 | 90 | 0.5 |
| IF 101 | 30 | 2 | 90 | 0.5 |
| IF 102 | 30 | 10 | 80 | 0.1 |
| IF 103 | 42 | 2 | 90 | 0.5 |
| IF 104 | 60 | 10 | 80 | 0.1 |

All impedances are 50Ω in and out. Power required is +22 vdc.

## HIGH POWER IF AMPLIFIER SERIES IF 300

**GENERAL DESCRIPTION —** All Solid state amplifier combining high voltage and power gain in one compact, ruggedized package.

**SPECIFICATIONS:**

Center Frequency — 60 Mc/s
Bandwidth — 7 Mc/s at 3 db points
Voltage Gain — 65 db
Input Impedance — 50 ohms
Output Impedance — 50 ohms
Linear Voltage Range — 0 to 9.5 volts RMS
Noise Figure — 8.5 db max.
Power Required +22 v.d.c. @ 350 ma
Size — 7⅜ x 3 x 1 inches plus connectors

Optional video output tap is provided with the following specifications:

Output Voltage — 12 volts peak
Output Impedance — 75 ohms
Rise Time — .1 microsecond max.
Fall Time — .2 microsecond max.

Combined unit weight for IF and video amplifiers — 17 oz.

Custom designed amplifiers in the IF 300 series are available with center frequencies up to 100 Mc/s.


## PULSED RF GENERATORS

These are tunnel diode pulsed RF generators with short turn-on and turn-off times, zero video feedthrough, close regulation to prevent FM or AM during the pulse, low input power, and high on-to-off voltage ratio. Video pulse voltage requirement is 6 volts peak; for CW operation, −22 volts at 4 ma are necessary. Units are supplied with any center frequency from 10 to 100 Mc. A front panel adjustment permits frequency change of ±20% of nominal center frequency. Units are typically 1½″ x 1″ x 1″. Connectors are BNC unless otherwise specified.

## REGULATED DC POWER SUPPLIES

Low-voltage, high-current transistorized power supplies are available with a wide choice of current/voltage rating combinations. Standard units may be selected with any combination of the following ratings: voltage, 6, 12, and 36 volts; current, 1, 2, 4, 6, 8, and 10 amps. Other combinations are available on request. Outputs are isolated from line permitting the grounding of either the plus or minus output terminal.

Supplies operate from 115V, 60 cps power. Up to four individual supplies can be mounted side by side behind a 19-inch rack panel.

Regulation (line and load combined) is ±.05%. Ripple is 1 mv peak-to-peak. A ±20% output voltage adjustment is available on each unit. Over-voltage protection and current limiting is standard. A complement of four supplies has overall dimensions of 19 x 8¾ x 20½ inches.

High voltage power supplies are available with outputs of 0 to 50KV at 5 ma in steps of 5 KV starting at the 5 KV level. These units operate from 115V, 60 or 400 cps power. Features include high reliability for military applications, all solid state components, low weight, and modular construction.

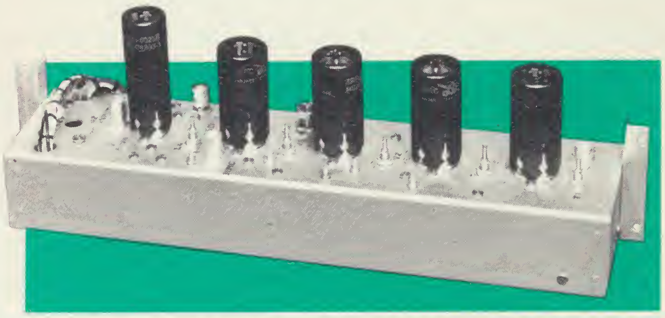
## TIME COMPRESSOR

The basic SUM memory can be furnished with external circuitry to comprise a time compressor system. This system translates low frequency incoming data to a higher frequency band with time compressed repetitive waveforms. Advantages offered by this system are many. To name a few: All solid state system with almost unlimited range of data rates and wide range of sampling periods — small size, high speed operation, low circuit complexity — time compression multiplies the frequency range and reduces output filter size requirements for the same integration — no information is lost the data stored is constantly updated — easily convertible system from time compression to permanent store mode.

Compression ratio in excess of 1000 may be obtained with output data rates up to 40 Mc/S.

## LIMITER-DISCRIMINATORS

LFE Limiter-Discriminators are highly accurate, ultra stable frequency sensitive detectors with linear deviation characteristics over a wide bandwidth. Available center frequencies range from 10 to 100 Mc. Bandwidth is greater than 40% of center frequency. Standard units have better than 5% linearity, with 1% available at a modest additional cost. All units exhibit low level limiting and high crossover stability. A typical specification is as follows:



### TYPICAL SPECIFICATION

| | |
|---|---|
| **Center Frequency** | 90 Mc |
| **Bandwidth (P-P)** | 40 Mc |
| **Input level** | 0 dbm. Lower level signals may be amplified |
| **Outputs** | For pulse outputs: wideband cathode follower (a-c coupled)<br>For AFC, etc.: direct coupled, with integrating circuit |
| **Temperature range** | −55°C to +80°C |
| **Output sensitivity** | 0.1V/Mc |
| **Linearity** | 1% for 80-100 Mc discriminator bandwidth |
| **Power Drain** | 25 watts |
| **Overall video bandwidth** | 50 cps to 8 Mc |

When ordering Limiter-Discriminator units, specify 1) Center Frequency 2) P-P Bandwidth 3) Linear Bandwidth and 4) Video Output Sensitivity in V/Mc.

## TEMPERATURE CONTROLLERS

**LFE Temperature Controllers** are true proportional temperature servos which furnish a continuous flow of power to the load. They have found wide application as heater control devices for ultrastable quartz ultrasonic delay line packages, for controlling the temperature of ultrastable oscillators (as well as complete circuits), temperature baths and other equipment requiring extremely close temperature control, reliability and long life. The units are all solid state, highly efficient, and small.

**Model TC20** uses a thermistor probe as a sensor and achieves accuracies of up to ±0.01°C depending on the application. The basic controller is furnished less thermistor probe, temperature setting resistor, and load resistor. Factory calibrated units are furnished with external thermistor probe and internal temperature setting resistor, but less load resistor.

**Model TC40** uses a resistance wire as the negative feedback element to monitor continuously the load temperature and adjust the controller output to maintain the load temperature at the set value. It achieves accuracies of up to ±0.001°C depending on the application. The basic controller is furnished less the resistance temperature sensor and the load resistance.

### SPECIFICATIONS

| Parameter | TC20 | TC40 |
|---|---|---|
| Input | 115 v 60 cps. 106 VA for 100 watts output | 115v 60 cps. 82 VA for 80 watts output |
| Output | half wave, 100 watts max. | half wave, 80 watts max. |
| Control | Resistor bridge, thermistor controlled | Precision resistance bridge, resistance wire controlled |
| Sensor | Thermistor probe. 8-20K nominal resistance at desired temperature | 780Ω resistance wire with positive temperature coefficient |
| Sensitivity | 60Ω change in sensor resistance controls output voltage from 10% to 90% | 0.1 ohm sensor resistance change controls output voltage from 10% to 90% |
| Accuracy | Up to ±0.01°C depending on application. Controller output is zero with shorted thermistor terminals. | Up to ±0.001°C depending on application |
| Ambient | −55°C to +65°C | −55°C to +85°C |
| Enclosure | 4¼″ x 3⅝″ x 1¼″. Flange or back-of-panel mounting. | Hermetically sealed, stud mounting, solder pin connections. 4⅛ x 3½ x 1¼ inches. Other configurations available on request. |

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# DIGITAL Ultrasonic Delay Lines

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A DIVISION OF LABORATORY FOR ELECTRONICS, INC.

BOSTON, MASSACHUSETTS

## *EVOLUTION OF THE DIGITAL ULTRASONIC DELAY LINE*

*With the advent of present-day, high-speed miniaturized computer circuitry, many conventional serial memory devices — such as magnetic drums, tapes and discs, and magnetostrictive delay lines — have been rendered almost obsolete. In effect, the search for memory devices compatible with such circuitry has resulted in the development of a new family of solid-state delay devices, based on conventional ultrasonic delay line technology — Digital Ultrasonic Delay Lines. Unlike conventional ultrasonic delay lines, these devices are designed to:*

- *Operate without an RF carrier;*
- *Handle digital data in the form of video pulses, and;*
- *Provide minimum distortion and loss.*

*Bit rates from 0.5 to 40 megacycles, with storage capacities well in excess of 20,000 bits, are presently achievable. The basic theory and processes involved in the design of digital delay lines, as well as typical parameters, applications, test methods and specification procedures, are outlined in the following paragraphs.*

## SOLID ULTRASONIC DELAY LINES

Ultrasonic delay lines make use of the relatively slow velocity of acoustic waves through dense solid media to achieve long delays in relatively small space. The electrical signals to be delayed are converted into acoustic waves by the input transducer affixed to the delay medium (see Figure 1). Upon reaching the output transducer, the acoustic signal is reconverted into an electrical signal delayed by a time interval equal to the propagation time through the delay medium. To conserve space and material, the acoustic beam path may be folded one or several times, as shown in Figure 2. Since the transducers are resonant devices, a solid delay line acts as a bandpass network with a frequency of minimum attenuation in the vicinity of the transducers' resonant frequency.

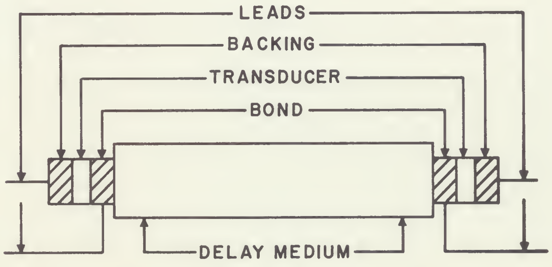


**Figure 1.** Solid Ultrasonic Delay Line

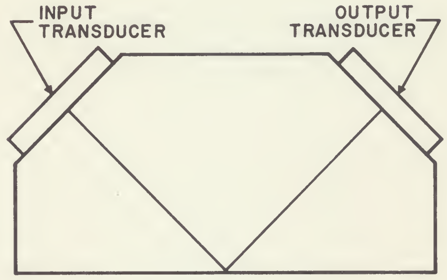


**Figure 2.** Ultrasonic Delay Line with Folded Acoustic Path

### Digital vs. Conventional Delay Lines

In conventional ultrasonic delay lines, the information to be delayed modulates an RF carrier whose frequency is equal to the center frequency of the delay line; the delayed signal is then amplified and detected. This scheme permits operation of the delay line in its most efficient mode, and does not impose strict limits upon bandwidth and dispersion requirements.

If a video pulse is applied to a conventional ultrasonic delay line, its frequency components are essentially analyzed in the time domain, with the higher frequency components delayed less and arriving first (Figure 3); the resulting pulse is highly distorted. Digital delay lines, however, are corrected for this type of distortion, with the result that a delayed video pulse approximates the typical pulse response of the ideal bandpass filter with linear phase shift (see Figure 4). For a delay line with a given center frequency, the optimal video pulse width should be equal to approximately one-half the period of the center frequency. If the line is operating in an RZ mode, the pulse spacing is equal to the pulse width, and the maximum bit rate of the line is equal to the nominal center frequency.

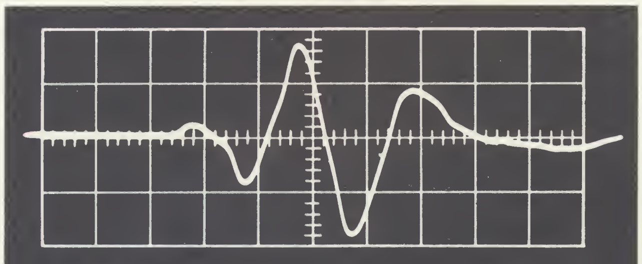

**Figure 3.** Dispersion in Acoustic Delay Line

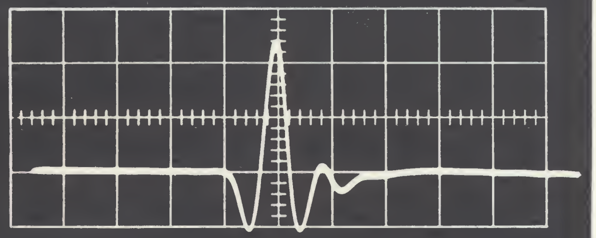

**Figure 4.** Output Pulse, Non-Dispersive Acoustic Delay Line

### Glass vs. Quartz Medium

Until recently, the standard medium for ultrasonic delay lines has been fused quartz, which combines excellent loss properties over a wide frequency range with good handling and manufacturing characteristics, and which provides a good impedance match with commonly used transducer materials. The major disadvantage of quartz, however, lies in its high temperature coefficient (−70 to −80 ppm/°C). Various glass compositions exhibiting low temperature coefficient and adequate loss characteristics have been developed for use in digital delay lines. These glasses have a temperature coefficient of zero at one specific temperature within the 20 to 50°C range, and a linear change in temperature coefficient on either side of this minimum. Figure 5 illustrates the temperature characteristics of the zero-temperature-coefficient glass used by the Advanced Components Operation of LFE Electronics in the manufacture of digital delay lines.

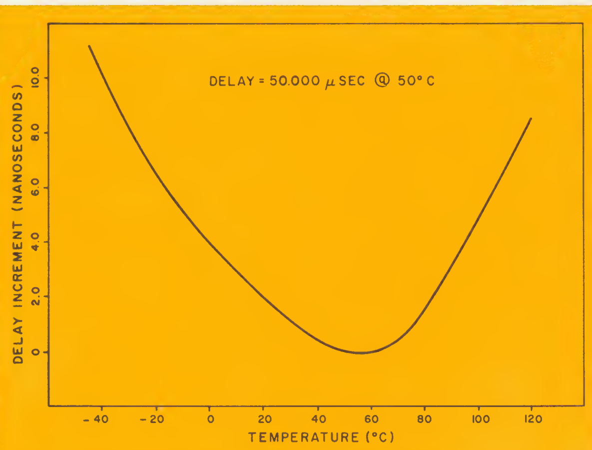


**Figure 5.** Delay vs. Temperature Characteristics — Zero-Temperature-Coefficient Glass Delay Lines

Besides eliminating the need for close temperature control in most applications, zero-temperature-coefficient glass exhibits an acoustic impedance which closely matches that of quartz transducers. This characteristic yields wide bandwidths and minimizes transducer ringing, which is a major source of distortion. Acoustic losses are somewhat greater than in fused quartz, with the result that the use of zero-temperature-coefficient glass is restricted to relatively short delay lines.

Transducer materials used in solid digital delay lines fall into two categories — crystalline quartz and piezoelectric ceramics. Quartz crystals are relatively low efficiency devices (coupling coefficient = 0.14) with resultant high radiation resistances; since the quartz crystal is essentially a constant current device, changing the load resistance will change the output voltage level. The low dielectric constant of quartz yields low transducer capacities even at very high frequencies. Piezoelectric ceramics, such as barium titanate, lead zirconate titanate (PZT), or lead metaniobate, are characterized by high coupling coefficients (0.7 and above) which result in low radiation resistances. Their very high dielectric constants prevent their application to high frequency delay lines unless special techniques are made use of to limit transducer capacitance.

## DEFINITIONS AND MEASUREMENTS

Most parameters of concern in digital lines — such as capacity and attenuation — are conventional and require no special definitions; however, special characteristics require some elaboration. The waveforms presented below (Figures 6 and 7) illustrate some of these characteristics. Figure 8 outlines a typical test setup for measuring delay, attenuation, and spurious levels.

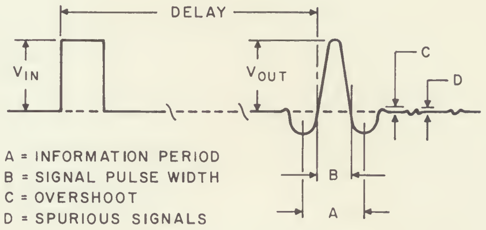


**Figure 6.** Waveform Definitions — RZ Mode

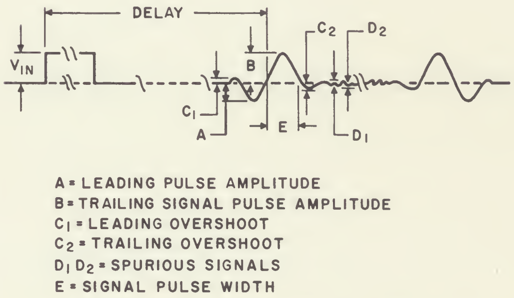


**Figure 7.** Waveform Definitions — NRZ Mode

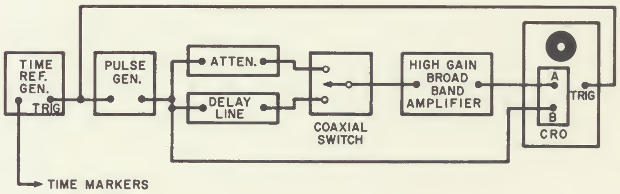


**Figure 8.** Typical Test Setup for Digital Delay Lines

## APPLICATIONS

In the field of data processing, digital ultrasonic delay lines have found wide application as serial memory elements for bulk and buffer storage, as scratch-pad memories, shift registers and trigger delay devices, or for pulse-shaping purposes. The high storage capabilities, mechanical ruggedness, and electrical and chemical stability of digital ultrasonic delay lines also suggest their utilization in many space, missile and communication applications.

A typical recirculating memory system employing a digital ultrasonic delay line is illustrated in Figure 9.

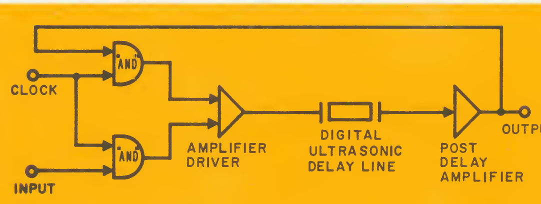


**Figure 9.** Serial Memory Package Employing Digital Delay Line

## GENERAL CHARACTERISTICS OF DIGITAL DELAY LINES

| | Quartz-Quartz | Ceramic-Quartz | Quartz-Glass | Ceramic-Glass |
|---|---|---|---|---|
| **Delay Range** | 1-1000 $\mu$sec | 1-1000 $\mu$sec | 1-150 $\mu$sec | 1-150 $\mu$sec |
| **Bit Rate or Center Frequency Range** | 5-40 Mc | 3-25 Mc | 5-40 Mc | 0.5-25 Mc |
| **Bit Length Range** | 10-100 nsec | 20-150 nsec | 10-100 nsec | 20-1200 nsec |
| **Transducer Capacity Range** | 25-150 pF | 50-10,000 pF | 25-150 pF | 50-10,000 pF |
| **Attenuation Range** | 40-80 db into 50 ohms | 20-60 db into 50 ohms | 30-80 db into 50 ohms | 20-80 db into 50 ohms |
| **Typical Signal/Noise Ratio** | 10-20/1 | 10-20/1 | 15-25/1 | 5-15/1 |
| **Temperature Coefficient of Delay** | −75ppm/°C ±5ppm/°C | −75ppm/°C ±5ppm/°C | See Fig. 5 | See Fig. 5 |
| **Radiation Resistance (Typical)** | 500-10,000 ohms | 1-200 ohms | 2000-8000 ohms | 1-200 ohms |

Note: Digital delay lines are generally encased in metal cans, both for shielding purposes and for mechanical stability. Packages designed for hostile environments or to military specifications can also be provided. A variety of painted or plated finishes are available.

## SPECIFYING DIGITAL DELAY LINES

Specifications should include the following:

(1) Total delay, or total storage capacity, and tolerances
(2) Maximum bit rate
(3) Mode of operation (RZ or NRZ)
(4) Video pulse or bit characteristics: width, amplitude, rise and fall times, etc.
(5) Signal-to-noise ratio
(6) Input and output admittances
(7) Load resistance
(8) Pulse attenuation
(9) Operating temperature range, and stability within that range; in the event that quartz is to be used as the delay medium, state power available for heaters and expected ambient levels
(10) Physical size, packaging, and type of connectors
(11) Environmental requirements

A general description of the application, with schematics of driving and amplifying circuitry, is also useful.

## SPECIAL DIGITAL UNITS

In addition to the conventional digital delay lines described above, the Advanced Components Operation of LFE Electronics offers delay or memory packages for special requirements.

These include:

- Tapped delay lines
- Digital echo lines
- Multiple-channel delay lines
- Adjustable delay lines
- Isothermal quartz delay line packages, incorporating heaters and associated control circuits
- Multipackages incorporating two or more delay lines
- Complete serial memory systems

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